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A 20 YEARS' SURVEY OF LASER SCIENCE AND TECHNOLOGY IN CHINA. II--ETC(U)
OCT 80 J ZHONG, Q LI
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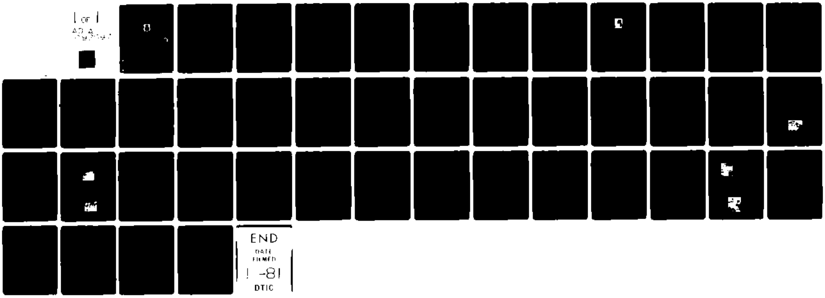

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FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

A 20 YEARS' SURVEY OF LASER SCIENCE
AND TECHNOLOGY IN CHINA (II)

by

Ji Zhong, Qun Li

FOREIGN TECHNOLOGY DIVISION

EDITED TRANSLATION

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A 20 Years' Survey of Laser Science and Technology in China (II)

The Correspondent Ji Zhong
The Reporter Qun Li

LASER ELEMENTS

The development and manufacture of various elements, such as laser working material, light sources, and reflecting film, played an important role in the evolution of China's laser science and technology. These elements have direct effects on the performance of lasers and they created the conditions which led to the successful operation of lasers in the years of the 1960's when competitive developments were taking place. As the technology of laser applications becomes more sophisticated and leads to practical uses, higher requirements are placed on the laser elements. Therefore, a broadened research effort on laser elements to improve their quality is of key importance in widening the laser applications.

Laser working material is the most important of the elements. China started making ruby laser material in 1961 and reached advanced international standard in many properties in the mid 1960's. At that time, joint efforts were launched by relevant departments to reach the goal of obtaining large crystals. Efforts were eventually halted because the product quality, evidently inferior to that of neodymium glass, could not meet the application requirements and little use was made of it due to the gap between research and production. In recent years, research on ruby laser material has continued and improved. For instance, the Laser Institute in Jiaozuo, Henan, employed flame melt method in the production of ruby crystals and the improved technique led to laser efficiency of approximately 1% (1.7%

maximum) and this Institute has supplied over 3000 laser rods to nearly one hundred units in China in the past few years. Also, the Anhui Institute of Optics and Precision Instruments, Chinese Academy of Science and several other research units have grown ruby crystals using the pulling method which has substantially improved the optical quality of the material and the laser light beam.

Comparision of ruby crystal characteristics grown by flame melt method and pulling method

Method of growth	Divergence	Threshold Value	Efficiency	Research unit, date and status status
Flame melt method	$\leq$ 5 mR	ϕ 10x150 rod 700 Joules	0.8% ave. 1.7% max.	Jiazuo Institute, 1970, passed specification, batch production.
Pulling	3 mR End faces need no optical finish	10% lower than flame rod melt	>0.7%	Anhui Institute started late 1974, in development stage.

In the actual research work on neodymium glass, China is one of the countries with a large scale research effort. There has been a combined force involving more than ten research institutes and factories to carry out research in all aspects from the

processing and purification of raw material, crucible melt techniques, formula composition, to the actual production. Large rods of ϕ 120x5000 mm have been obtained. They are considered unique in the world. The neodymium glass research work*, after more than 10 years efforts, has achieved definite accomplishments in workmanship, formulation and theoretical research. The laser glasses developed and manufactured by the Shanghai Optics and Precision Machines Institute of the Chinese Academy of Science have reached advanced world standard in some of their properties and several models of their laser glasses are now being sold as export products. The tables below show the major characteristics of some of the export laser glasses.

*See "On the nonlinear refractive index of glass and its calculation method," Laser Journal, Vol. 6, No. 4, 12, 1979 and "Spectrum and emission characteristics of neodymium doped phosphate glass," Laser Journal, Vol. 6, No. 9, 23, 1979.

1 我国几种商品钕玻璃的性能

		2 型号		
		N_{1120}	N_{2113}	N_{0312}
Nd_2O_3	$(W+\%)$	3.0	1.2	1.3
3 受激发射截面	$(10^{-20}cm^2)$	2.5	3.5	1.2
4 荧光寿命	(μS)	300	350	590
5 荧光中心波长	(μ)	1.06	1.054	1.06
6 荧光半宽度	(μ)	270	265	290
7 1.06埃损耗系数	$(10^{-3}cm^{-1})$	1.0		1.5
8 激光效率	$(R=50)\%$	2.0 ($\phi 6\times 150$mm)		4.0 ($\phi 16\times 500$nm)
nD		1.560	1.531	1.522
ν		58.0	64.4	59.8
9 折射率温度系数	(6328 埃 10) $(10^{-7}/°C)$	24	−58	16.4
11 热膨胀系数	$(10^{-7}/°C)$	105 (20～400°C)	117 (20～400°C)	115
12 热光系数	$(10^{-7}/°C)$	71	7.1	58
13 应力热光系数	$(10^{-7}/°C)$		7	
14 双折射热光系数	$(10^{-7}/°C)$		4	
15 转变温度	(°C)	465	497	
16 变形温度	(°C)	500	530	
17 密度	(g/cm^3)	2.61	3.20	2.51
18 弹性模数	(kg/mm^2)	8860	5860	
19 剪切模数	(kg/mm^2)	3600		
20 泊松比		0.231		

Key:

1. Properties of several Chinese commercial neodymiun glasses
2. Model Number
3. Stimulated emission cross-section
4. Fluorescence life
5. Fluorescence center wavelength
6. Fluorescence halfwidth
7. Attenuation coefficient at 1.06 Angstrom
8. Laser efficiency
9. Temperature coefficient of refractive index
10. Angstrom
11. Thermal expansion coefficient
12. Thermo-optical coefficient
13. Stress thermo-optical coefficient
14. Double refraction thermo-optical coefficient
15. Transition temperature
16. Deformation temperature
17. Density

18. Elastic modules
19. Shear mdoules
20. Poisson's ratio

1 几种玻璃的物理性质和工艺性质

4 型号	2 物理性质						3 工艺性质		
	5 密度 (克/厘米³)	6 显微硬度 (公斤/毫米²)	7 机械强度 (公斤/毫米²)	8 弹性模量 (10^3公斤/厘米²)	9 膨胀系数 $10^{-7}°C^{-1}$		10 转变温度 T_g(°C)	11 软化温度 T_f(°C)	粘度100泊时的温度 12 (°C)
					15°C~200°C	15°C~T_g			
N[illegible]	2.90	560	9.7	679	90	104	500	590	1400
N[illegible]	2.87	560	9.0	720	88	91	560	630	1380
N[illegible]	2.51	606	11.8	759	80	88	590	660	1480
N[illegible]	2.49	615	9.4	727	52	57	590	670	1680
N[illegible]	2.52	628	10.4	810	87	98	555	610	1270
N_{0713}	2.52	557	9.1	647	89	96	495	560	1470
N[illegible]	2.80	551	9.1	647	107	120	545	600	1440
N[illegible]	2.50	583	10.2	687	87	98	620	680	1450
N_{1024}	2.52	585	8.9	750	89	100	525	585	1420

Key:

1. Physical and technical properties of some glasses
2. Physical properties
3. Technical properties
4. Model number
5. Density (g/cm^3)
6. Microhardness, (Kg/mm^2)
7. Mechanical strength, Kg/mm^2)
8. Elastic modules, $(10^3 Kg/cm^2)$
9. Expansion coefficient
10. Transition temperature
11. Softening temperature
12. Temperature for 100 poise viscosity

1 我國几种钕玻璃的荧光和激光性能

2 型 号	3 荧光寿命(微秒)	4 1.06 微光荧光半宽度(毫微米)	5 φ16×500 毫米棒的激光效率	6 1.06 微米吸收系数(%/厘米)	7 研制年分	8 备 注
N_{0112}	600	27	2.4	0.2	1962	已定型 9
N_{0212}	620	28	3.0	0.1		未定型 10
N_{0312}	590	29	4.0	0.1	1967	已定型 11
N_{0412}	680	28	3.8	0.16	1968	未定型 12
N_{0612}	680	27	2.2	0.29		未定型 13
N_{0712}	890	24	3.5	0.12	1970	已定型 14
N_{0812}	760	28	2.7	0.27		已定型 15
N_{0912}	750	24	3.8	0.1		已定型 16
N_{1006}	810	28	3.5	0.22	1971	已定型 17

Key:

1. Fluorescence and laser properties of some Chinese-made neodymium glasses
2. Model number
3. Fluorescence life (microsecond)
4. 1.06 micron fluorescence half width (millimicron)
5. φ 16x500 mm rod laser efficiency
6. absorption coefficient for 1.06 micron (%/cm)
7. Production year
8. Remark

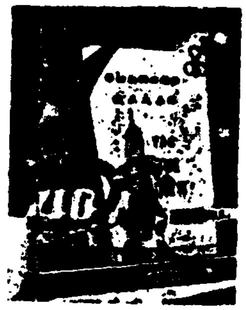
9, 11, 14-17. Finalized
10, 12, 13. Not finalized

In addition, early laser working materials also include neodymium doped calcium tungstate, uranium doped calcium fluoride and dysprosium doped calcium fluoride crystals* and these laser materials have all achieved laser output.** However, the most widely used crystals today are still neodymium doped yttrium aluminum garnet (YAG) developed in 1965. Statistics showed that more than 40 research units in China have participated in YAG research. In recent years, reorganization has promoted quality and entered limited production state, but there are still approxi-

*"Preparing high quality calcium fluoride single crystals using zone melting crystallization," Science Bulletin [KEXUE TONGBAO], 1964, No. 2, 150.

**"Infrared stimulated emission of CaF_2: Dy^{2+} fluorescense crystal," Science Bulletin [KEXUE TONGBAO], 1964, No. 1, 56; "Infrared stimulated emission of CaF_2: U^{3+} fluorescence crystal," Science Bulletin [KEXUE TONGBAO], 1964, No. 1, 57, and "Neodymium doped calcium tungstate laser," Science Bulletin [KEXUE TONGBAO], 1965, No. 3, 827.

mately 20 units involved. The largest crystal obtainable has the dimensions of ϕ 40x200 mm and the highest energy conversion efficiency can be 2%. The figure below shows a large YAG crystal laser rod.



Among the YAG crystals, the ϕ 20 x 120 ~ 150 mm crystals, grown by North China Institute of Photoelectric Technology using medium frequency induction heating, low pulling speed and low rotation speed, generally have reliable quality and their continuous laser light power output can be as high as 150 watts. Both Shanghai Institute of Optics and Precision Instruments and North China Institute of Photoelectric technology have independently carried out research on doubly doped (Nd, Cr) YAG crystals and achieved continuous laser output of 165 watt power and 2.7% efficiency. Research on double dopes (Nd, Lu) YAG is being developed at Anhui Institute and basic theoretical exploration is being carried out at many other institutes.

The following table*** summarizes the measurement results of YAG crystals developed by various research units and participated in the Specialty Testing Conference held in Beijing in 1978.

***"Unified testing report on neodymium doped yttrium aluminum garnet (Nd: YAG) crystals," Laser and Infrared Journal, 1978, No. 10, 1.

1 YAG 晶体棒测量结果(1978 年 5 月)

2 (样品共 23 根, 来自 16 个单位, 现选刊 16 根样品的试验结果)

3 编号	4 单位	5 尺寸及加工情况	6 生长方式	7 测量单位	8 消光比 dB/5 厘米	9 内耗%/厘米$^{-1}$	10 大角散射 %/厘米$^{-1}$	11 静态脉冲工作				12 连续工作		
								18 阈值(焦耳)	19 斜率效率(%)	20 总输出(焦耳)	21 总效率(%)	22 阈值(瓦)	23 斜率效率(%)	24 总输出(瓦)
1	13 辽宁大学	φ5.4×78 /2′⊥2′ 14 平度 1/2 1/8, 光洁度, 不亮 15	电阻 16	I	26~29	2.4	0.26	2.7	1.12	0.75	1.04	1140	1.57	23.4
				II	26~30	3.3	14.0	3.2	1.55	0.93	1.27	1110	1.33	25
				III	25~30	7.9	0.86	7.6	1.14	1.05	1.05	504	1.54	24.6
				IV	20~24	2.7		4.5	1.32	0.78	0.96	1570	1.73	26
				17 暂定	26~30		0.26~0.86		1.32				1.73	

Key:

1. Measurement results on YAG crystal rods (May, 1978)
2. A total of 23 samples from 16 sources, published here are results on 16 of the samples
3. Assigned number
4. Source
5. Dimensions and worked condition
6. Growth method
7. Measured by
8. Attenuation ratio, dB/5cm
9. Internal loss, %/cm-1
10. Large angle scattering 2, %/cm^{-1}
11. Steady state pulsed operation
12. Continuous operation
13. Liaoning University
14. Flatness
15. Shininess, low
16. Resistive (heating)
17. Preliminary
18. Threshold value[3] (Joules)
19. Sloping efficieny (%)
20. Total output (Joules)
21. Total efficiency (%)
22. Threshold value (Watts)
23. Sloping efficiency (%)
24. Total output (Watts)

1(续表)

1. 编号	3 单位	4 尺寸及加工情况	5 生长方式	6 测量单位	7 消光比 db/5厘米	内耗%/厘米$^{-1}$ 8	大角散射%/厘米$^{-1}$ 9	10 静态脉冲工作 阈值(焦耳) 11	斜率效率(%) 12	总输出(焦耳) 13	总效率(%) 14	连续工作 15a 阈值(瓦) 15	斜率效率(%) 16	总输出(瓦) 17
2	18 鞍山金属材料厂	19 φ5.5×65 // 10″⊥30″ 平度 1/2 光洁度 V	20 电阻 Nd 2% 1.2毫米/小时 68转/分	I	10~17	4.8	0.95	4	1.15	0.62	0.97			1.28
				II	8~16	8.5	128	2.5	1.56	0.89	1.36	2840		3.5
				III	10~17	5.4		4.4	1.05	0.98	0.98	1090		4.8
				IV	6~10	3.4	2.26	2.5	1.23	0.74	1.00			2
				暂定 21	8~16		0.95~2.26		1.23					
3	22 北京物理所	23 φ5.4×79 // 15″⊥30″ 平度 1/5 光洁度 V	24 高频 Nd 5% 1.3毫米/小时 45转/分	I	25~29	1.0	0.25	1.0	0.9	0.70	0.90	990	2.05	85.2
				II	23~29	2.5	24.0	1.3	1.50	0.95	1.20	890	2.14	44
				III	21~27	1.0		1.3	1.88	1.41	1.41	490	3.40	42
				IV	18~22	2.5	1.12	1.7	1.96	1.54	1.70	1100	2.15	49
				暂定 25	23~29		0.25~1.12		1.96				2.15	
5	26 北京化工厂	27 φ5.5×76 // 1′⊥30″ 平度 1/4 光洁度，差	28 电阻	I	13~19	1.6	0.33	2.5	1.47	0.97	1.30	1400	0.48	6.2
				II	10~21	3.3	48	2.2	1.60	1.04	1.86	1480	0.90	12
				III	12~18	2.8		3.4	1.30	1.05	1.05	790	0.97	18
				IV	7~18	3.5	1.23	3.5	1.42	1.00	1.18	1460	1.20	20
				暂定 29	10~21		0.38~1.23		1.42				1.20	
7	30 华北光电所	31 φ5.5×75 // 30′⊥1′ 平度 1/8 1/4，光洁度 III，V	32 中频 双掺 1.24毫米/小时	I	27	1.4	0.21	1.8	1.56	0.98	1.82	966	1.40	29.7
				II	24~38	1.4	30.5	1.0	1.45	0.98	1.38	940	1.70	40
				III	29~38	3.1		2.7	1.39	0.96	0.96	490	1.40	26
				IV	29~33	1.8	5.30	1.8	1.32	1.08	1.26	1100	2.10	50
				暂定 33	24~38		0.21~5.30		1.32				2.10	
8	34 上海光机所	φ5.5×73	35 电阻 Nd 3% 2毫米/小时 90~50转/分	I	27~33	1.1	0.3	1.6	1.14	0.77	1.07	1380	1.10	13.1
				II	24~32	2.4	38	1.3	1.4	0.91	1.24	1220	1.50	24
				III	25~35	2.4		3.1	1.1	1.02	1.0	580	1.10	19.2
				IV	21~28	2.9	0.86	2.0	1.3	0.95	1.05	1490	1.61	28
				暂定 36	24~32		0.3~0.86		1.3				1.61	
11	37 上海东方仪表厂	φ5.5×71 / 40″⊥30″ 平度 1/2 光洁度，不亮 38	39 电阻	I	26~30	1.8	0.19	2.5	1.54	1.00	1.42	1070	1.90	24.9
				II	22~28	2.7	13	1.4	1.98	1.18	1.68	970	2.10	38
				III	21~31	3.6		3.6	1.10	0.99	1.00	440	1.70	26.5
				IV	17~19	2.8	0.9	1.7	2.00	1.29	1.60	1180	2.50	47
				暂定 40	22~28		0.19~0.90		2.00				2.50	
14	41 扬州5806厂	42 φ5.6×71 / 10″⊥1′ 平度 1/4 光洁度 V	43 电阻	I	31	1.1	0.3	1.3	1.52	0.96	1.37	1080	1.72	28
				II	29~32	1.9	26	1.2	2.0	1.33	1.37	1290	1.72	32
				III	26~29	3.3		4.0	1.3	1.20	1.20	420	1.60	25
				IV	24~27	2.3	1.1	1.7	1.4	1.04	1.30	1280	1.72	31
				暂定 44	29~32		0.3~1.1		1.4				1.72	
15	45 华东工程学院	φ5.9×70 / 10″⊥1′ 平度 1 光洁度 III，V 46	47 电阻	I	15~18	1.4	0.26	1.2	1.54	1.0	1.45	1364	1.2	11.8
				II	12~14	1.5	15.0	0.7	1.71	1.2	1.70	1240	1.78	30
				III	15~18	1.2		2.2	1.40	1.2	1.20	560	1.1	18
				IV	8~9	1.8	0.98	1.3	1.88	1.29	1.65	1490	1.2	20
				暂定 48	12~14		0.26~0.98		1.88				1.2	

Key:

1. (Continuation of Table)
2. Assigned number
3. Source
4. Dimensions and condition
5. Growth method
6. Measured by[1]
7. Attenuation ratio, db/5 cm
8. Internal loss, %/cm^{-1}
9. Large angle scattering[2], %/cm^{-1}
10. Steady state pulsed operation
11. Threshold value[3] (Joules)
12. Slope efficiency (%)
13. Total output (Joules
14. Total efficiency (%)

15a. Continuous operation

15. Threshold value (Watts)
16. Slope efficiency (%)
17. Total output (Watts)
18. Anshan Metal Materials Plant
19. Flatness 1/2; Shininess V
20. Resistive Nd 2%, 1.2 mm/hr., 68 rev./min.
21. Preliminary
22. Beijing Institute of Physics
23. Flatness 1/5; Shininess V
24. High frequency, Nd 5%, 1.3 mm/hr., 45 rev./min.
25. Preliminary
26. Beijing Chemical Engineering Plant
27. Flatness 1/4; Shininess, poor
28. Resistive
29. Preliminary
30. North China Institute of Photoelectric Technology
31. Flatness 1/3; Shininess III, V
32. Medium frequency, double doping, 1.24 mm/hr.
33. Preliminary
34. Shanghai Institute of Optics and Precision Instruments
35. Resistive, Nd 3%, 2 mm/hr., 90-50 rev./min.
36. Preliminary
37. Shanghai Eastern Indicating Instruments Plant
38. Flatness 1/2; Shininess, poor
39. Resistive
40. Preliminary
41. Yangzhou 5308 plant
42. Flatness 1/4; Shininess V
43. Resistive
44. Preliminary
45. East China Engineering College
46. Flatness 1; Shininess III, V
47. Resistive
48. Preliminary

(续表)

编号	单位	尺寸及加工情况	生长方式	测量单位	消光比db/5厘米	内耗%/厘米$^{-1}$	大角散射%/厘米$^{-1}$	静态脉冲工作 阈值(焦耳)	斜率效率(%)	总输出(焦耳)	总效率(%)	连续工作 阈值(瓦)	斜率效率(%)	总输出(瓦)
17	南京玻璃厂	φ5.6×70 //5″⊥15″ 平度1½ 光洁度III	高频 Nd3% 1.3毫米/小时 60转/分	I	13~15	2.3	0.27	1.4	1.28	0.92	1.33	1140	1.0	19.7
				II	11~15	1.2	33	0.8	1.78	1.20	1.72	1310	1.0	19
				III	11~15	3.0		2.5	1.40	0.93	0.90	600	0.97	14.4
				IV	7~10	2.0	1.07	1.5	1.53	1.13	1.45	1650	1.1	21
				暂定	11~15		0.27~1.07		1.53				1.1	
18	济南半导体厂	φ5.5×69 //30″⊥30″ 平度1/5 光洁度,差	电阻	I	25~29	1.8	0.42	1.5	1.95	1.21	1.78	1390	1.2	11.3
				II	22~30	1.8	34	1.0	1.58	1.0	1.45	1270	1.1	18.5
				III	23~28	3.7		2.3	1.4	1.1	1.1	560	1.0	12.9
				IV	9~26	2.5	1.05	1.8	1.7	1.28	1.6	1580	1.3	21
				暂定	22~30		0.42~1.05		1.7				1.3	
19	五机部209所	φ5.4×71 /5″⊥1′ 平度1/4 光洁度III	电阻 Nd3.5%	I	4~6	1.0	0.26	1.0	2.21			945	2.48	37.3
				II	4~8	1.7	11	0.7	2.50	1.74	2.45	970	2.51	41
				III	5~7	4.8		3.5	1.70	1.26	1.26	420	2.0	29
				IV	3~4	2.3	0.86	1.1	1.73	1.26	1.50	1170	2.1	43
				暂定	4~8		0.26~0.86		1.73				2.1	
20	成都206厂	φ5.5×78 //30″⊥30″ 平度1/3 光洁度II III	电阻 1.5毫米/小时 95~98转/分	I	25~27	1.2	0.37	1.0	1.57	1.08	1.5	1130	1.5	23.4
				II	20~26	1.4	16	0.7	1.34	0.97	1.32	970	1.9	38
				III	20~23	2.8		2.3	1.30	1.14	1.14	540	4.0	48
				IV	15~19	1.5	0.99	1.3	1.48	0.94	1.10	1270	1.8	42
				暂定	20~26		0.37~0.99		1.48				1.8	
21	成都半导体厂	φ5.5×70.5 //10″⊥15″ 平度1/8 光洁度V VI	电阻 Nd3% 1.33毫米/小时 83转/分	I	23~29	1.0	0.24	1.2	1.37	0.92	1.31	1160	1.73	24
				II	22~25	1.5	16	0.8	1.6	1.03	1.45	1120	1.54	35
				III	21~26	1.3		2.8	1.15	1.11	1.11	490	3.40	36
				IV	16~22	1.5	0.75	1.5	1.4	0.95	1.20	1300	1.73	35
				暂定	22~25		0.24~0.75		1.4				1.73	
22	三机部613所	φ5.7×76 //30″⊥1″ 平度1/3 光洁度,差	掺 Nd4% La7.2%	I	27~30	1.3	0.41	1.5	1.12	0.92	1.22	1480	1.03	12
				II	15~28	2.5	19	1.1	1.3	0.97	1.33	1370		28
				III	18~28	3.3		2.8	1.17	0.99	0.99	560	0.92	13
				IV	11~22	3.0	0.95	1.8	1.76	1.38	1.60	1720	1.0	16
				暂定	15~28		0.41~0.95		1.76				1.0	
23	五机部205所	φ5.5×72 /15″⊥2′ 平度1/2 1/4,光洁度III	电阻 1.5毫米/小时 84转/分	I	19~22	3	1.44	3.1	1.06	0.68	0.94			
				II	17~20	1	138	2.2	1.50	0.95	1.32			
				III	19~22	5		5.2	0.8	0.66	0.66			1
				IV	13~15	4	2.0	3.9	1.2	0.78	0.9			
				暂定	17~20		1.44~2.0		1.2					

[Translation of the Table on page 11]

Key:

1. (Continua on of Table)
2. Assigned number
3. Source
4. Dimensions and condition
5. Growth method
6. Measured by[1]
7. Attenuation ratio, db/5 cm
8. Internal loss, $\%/cm^{-1}$
9. Large angle scattering[2], $\%/cm^{-1}$
10. Steady state pulsed operation
11. Threshold value[3], (Joules)
12. Slope efficiency, %
13. Total output (Joules)
14. Total efficiency, %
15. Continuous operation
16. Threshold value (Watts)
17. Slope efficiency, %
18. Total output (Watts)
19. Nanjing Glass Plant
20. Flatness 1/2; Shininess III
21. High frequency, Nd 3%, 1.3 mm/hr., 60 rev./min.
22. Preliminary
23. Jinan Semiconductor Plant
24. Flatness 1/5; Shininess, poor
25. Resistive
26. Preliminary
27. 209 Institute, 5th Ministry of Machine Building
28. Flatness 1/4; Shininess III
29. Resistive, Nd 3.5%
30. Preliminary
31. Chengdu 208 Plant
32. Flatness 1/3; Shininess II III
33. Resistive, 1.5 mm/hr., 95-98 rev./min
34. Preliminary
35. Chengdu Semiconductor Plant
36. Flatness 1/8; Shininess V VI
37. Resistive,Nd 3%, 1.33 mm/hr., 83 rev/min.
38. Preliminary
39. 613 Institute, 3rd Ministry of Machine Building
40. Flatness 1/3; Shininess poor
41. Doping Nd 4%, Lu 7.2%
42. Preliminary
43. 205 Institute, 5th Ministry of Machine Building
44. Flatness 1/2, 1/4; Shininess III
45. Resistive, 1.5 mm/hr., 84 rev./min.
46. Preliminary

[Footnotes at bottom of previous Table, page 11]

1 Measurements made by: I. Shanghai Institute of Optics and Precision Instruments; II. Shanghai Eastern Indicating Instruments Plant; III. Shandong University; IV. North China Institute of Photoelectric Technology. For the preliminary values, attenuation ratios are based on the data by Shanghai Eastern Indicating Instruments Plant, large angle scatterings are based the data by Shanghai Institute of Optics and Precision Instruments and by North China Institute of Photoelectric Technology, Steady state efficiency and continuous slope data are from North China Institute.

2 Large angle scattering: Shanghai Institute of Optics and Precision Instruments used 1.06 micron light source and North China Institute of Photoelectric Technology used 6328 Å light source.

3 In the steady state pulsed laser testing, the Shandong University data tend to be too low because their measurements are made with an added socket tube.

4 Measurement conditions: Input power used by the Shanghai Institute and the Eastern Plant was 3 kilowatt, Shandong University used 2.5 Kilowatt and the North China Institute used 4.3 Kilowatt.

There are also quite a few institutes in China engaged in the development of new laser crystal materials such as neodymium yttrium aluminate, neodymium penta phosphate, neodymium lithium tetra phosphate, lithium fluoride, gadolinium molybdenate, and so forth, and they have all successfully achieved lasing. The following table lists some of the new crystal materials investigated by the North China Institute of Photoelectric Technology.

1 晶体名称	2 研制日期
3 掺钕氟磷酸钙	1971
4 掺钕硅酸氧钇钙	1973
5 掺铒氟化钇锂	1977
6 掺钬钼酸钆	1978
7 掺钬氟化钇锂	1978
8 掺钕多铝酸镧	1978
9 掺铽氧化钇钙	1978
10 掺钕钒酸钇	1979
11 双掺铽镝钼酸钆	1979
12 掺钕钼酸钆	1979
13 钼酸钆	1979
14 掺铒钼酸钆	
15 掺铽钼酸钆	

Key:

1. Crystal name
2. Development date
3. Neodymium doped calcium fluoro-phosphate
4. Neodymium doped calcium yttrium oxygen silicate
5. Erbium doped yttrium tithium fluoride
6. Holmiun doped gadolinium molybdenate
7. Holmium doped yttrium lithium fluoride
8. Neodymium doped lanthanum polyaluminate
9. Terbium doped yttrium lithium oxide
10. Neodymium doped yttrium vanadate
11. Terbium and dysprosium doped gadolinium molybdenate
12. Neodymium doped gadolinium molybdenate
13. Gadolinium molybdenate
14. Erbium doped gadolinium molybdenate
15. Terbium doped gadolinium molybdenate

The research of laser light source accommodates the development of laser components. According to types of light sources, there are high energy pulsed xenon lamp, high power pulsed xenon lamp, repeated frequency xenon lamp and continuous Krypton lamp. According to shape and structure, there are spiral, straight tube and coaxial types, although the straight tube light pumps are most common. The industrial technology of light source production had gone through major advances in recent years; as a result, the life and load of light sources have been substantially increased.

1. With friction spread indium seal techniques, gas tight joints between quartz, glass and copper, silver with leak rate less than 10^{-11} torr-liter/sec have been realized.

2. In the new technique of quartz-tungsten rod high temperature sealing, glass is used as a transition layer of the quartz-tungsten rod seal. Such seals can work under 700 ∿ 800°C over extended periods of time with sealability better than 10^{-10} torr-liter/sec. The largest tungsten rod sealable today is one with 4 mm diameter.

3. The copper cap and lead filling technique allow us to seal ϕ 150 ∿ 200 mm diameter quartz tubes.

The following five tables show the properties and the development of light pump light sources in China.

1 大能量脉冲氙灯

2 代号	3 尺寸				8 方波放电参数		极限负载	电阻率
	4 灯长(毫米)	极间距 5 (毫米)	外径 6 (毫米)	内径 7 (毫米)	电容 9 (微法)	放电时间 10 (毫微秒)	11 (焦耳)	(欧姆·厘米) 12
TEP-50×310	520	310	50	45	21600	20	35×10^4	~0.03
TEP-50×500	710	500	50	45	21600	20	57×10^4	~0.03
TEP-50×1000	1210	1000	50	45	21600	20	115×10^4	~0.03
TEP-50×1800	2010	1800	50	45	21600	10	156×10^4	~0.023
	2010	1800	50	45	21600	20	212×10^4	~0.028
	2010	1800	50	45	21600	40	360×10^4	~0.031
TEP-50×2250	2460	2250	50	45	21600	20	258×10^4	~0.023

Key:

1. Large energy pulsed xenon lamps
2. Designation
3. Dimensions
4. Lamp length (mm)
5. Electrodes distance (mm)
6. Outer diameter (mm)
7. Inner diameter (mm)
8. Square wave discharge parameters
9. Capacitance (microfarads)
10. Discharge time (nanoseconds)
11. Limiting load (Joules)
12. Resistivity (Ohm-cm)

1 大功率脉冲氙灯

2 代号	3 尺寸				8 使用参数							极限负载
	灯长(毫米)	极间距(毫米)	外径(毫米)	内径(毫米)	电容(微法)	工作电压(千伏)	放电脉宽(毫秒)	辐射效率(%)	灯电阻(欧姆)	点燃频率(次/分)	使用寿命(次)	(万焦耳) 16
TMS-15×500	4	5	6	7	9	10	11	12	13	14	15	
TMS-20×480	680	480	20	16	900	4.5	0.43	60	0.48	1	>2000	1.5
TMS-25×500	700	500	25	21.	2000	4	0.40	60	0.35	1	>2000	2.5
TMS-30×480	680	480	30	26	3000	4	0.50	60	0.23	1	>2000	3.0
TMS-35×600	800	600	35	31	3000	4	0.78	55	0.26	1	>2000	6.5
TMS-35×1100	1300	1100	35	31	1750	7	1.2	55	0.70	1	>1000	8.0
TMS-50×330	550	330	50	45	4000	4	0.8	40	0.05	1	>100	5.5

17 * "氙灯泵浦的NdP_5O_{14}晶体微型脉冲激光器已出光",《激光》, 1979, 6, No 6, 62; "五磷酸钕激光器",《激光》, 1979, 6, No 12, 16.

Key:

1. Large power pulsed xenon lamps
2. Destination
3. Dimensions

4. Lamp length (mm)
5. Electrodes distance (mm)
6. Outer diameter (mm)
7. Inner diameter (mm)
8. Operating parameters
9. Capacitance (microfarads)
10. Working voltage (kV)
11. Discharge pulse width (millisec)
12. Radiation efficiency (%)
13. Lamp resistance (Ohms)
14. Firing frequency (times/min.)
15. Usable life (times)
16. Limiting load (in 10^4 Joules)
17. "There is light from xenon lamp pumped Nd P_5O_{14} crystal miniature laser," Laser Journal, 1979, Vol. 6, No. 6, 62; "Neodymium penta phosphate laser," Laser Journal, 1979, Vol. 6, No. 12, 16.

1 重复频率脉冲氙灯

2 代号	3 尺寸 (毫米)				8 使用参数						
	4 灯长	5 极间距	6 外径	7 内径	9 最高电压 (伏)	10 频率 (次/秒)	11 单次能量 (焦耳)	12 爆炸能量 (焦耳)	13 脉宽 (毫微秒)	14 冷却水流量 (立升/分)	15 寿命 (脉冲次数)
GPMX-8×50	150	50	8	6	800	20~100	20	300	70	>6	$>10^7$
GPMX-8×70	170	70	8	6	1150	20~100	30	500	70	>6	$>10^7$
GPMX-8×120	210	120	8	6	1350	20~100	50	1200	100	>6	$>10^7$
GPMX-10×80	210	80	10	8	1350	20~100	70	1700	100	>6	$>10^7$
GPMX-10×100	212	100	10	8	2000	20~100	110	2500	150	>6	$>10^7$
GPMX-12×100	233	100	12	9	1350	20~100	90	2000	150	>6	$>10^7$
GPMX-12×120	242	120	12	9	2000	20~100	135	3000	180	>6	$>10^7$
DPMX-8×110	220	110	8	4	10000	20~40	10	400	<2	>6	$>10^6$

Key:

1. Repeated frequency pulsed xenon lamp
2. Designation
3. Dimensions (mm)
4. Lamp length
5. Electrodes distance
6. Outer diameter
7. Inner diameter
8. Operating parameters
9. Maximum voltage (volts)
10. Frequency (times/sec)
11. One-shot energy (Joules)
12. Expolsion energy (Joules)
13. Pulse width (nanoseconds)

14. Flow rate of cooling water (liters/min.)
15. Life (number of pulses)

1 连续氪弧灯

2 代号	3 尺寸 (毫米)				8 工作参数				
	灯长 4	极间距 5	外径 6	内径 7	工作电流 (安培) 9	工作电压 (伏) 10	功率 (瓦) 11	冷却水流量 (升/分) 12	累计使用寿命 (小时) 13
LK-8×75	200	75	8	6	35±2	132±3	4500	25	100
LK-10×100	235	100	10	8	44±2	136±3	6000	25	50
LK-10×120	255	120	10	8	48±2	167±3	8000	25	50

1. Continuous Krypton arc lamp
2. Designation
3. Dimensions (mm)
4. Lamp length
5. Electrodes distance
6. Outer diameter
7. Inner diameter
8. Operating parameters
9. Working current (Amp)
10. Working voltage (volts)
11. Power (Watts)
12. Flow rate of cooling water
13. Accumulated service life (hours)

China's laser thin film technology has been under continuous development and there is a compatible technology force and facility to match it. Development levels of the four major thin film technologies are listed in the following table and viewed in terms of the current demands on lasers.

1 我国激光薄膜现有水平

	2 波长	3 一般水平	4 最高水平
8 高反射膜	5 6328 埃 软膜 硬膜	6 (垂直反射率%) 99.5～99.8 90.0～99.5	7 (垂直反射率%) ～99.9 99.8～99.99
	9 1.06 微米 软膜 硬膜	 99.5～99.8 99.0～99.5	 99.8～99.9 ～99.8
		10 硬膜的抗激光强度：对1.06微米功率激光 >10 兆瓦/厘米², 对1.06微米 YAG 连续输出激光(光束～ϕ3)200 瓦正常使用。	
11 减反射膜	12 在可见至近红外区对单一波长	14 剩余反射率～0.1%	<0.05%
	13 1.06 微米 GaAs 窗口 Ge 窗口	15 透过率 >98% 透过率 >90%	16 抗激光强度 >1000 瓦/厘米² 抗激光强度 >100 瓦/厘米²
17 干涉滤光片	6328 6943 埃 18	21 半宽度 40～60 埃 透过率 70～75%	
	1.06 微米 19	22 半宽度 100 埃左右 透过率 70～75%	23 50 埃～55%
	1.06 微米* 20		700 埃≥40%
24 偏振膜	1.06 微米 25	26 s 分量透过率～2% p 分量透过率～96%	27 s 分量透过率～0.3% p 分量透过率～98%

Key:

1. Current level of Chinese laser thin film
2. Wavelength
3. Ordinary Level
4. Maximum level
5. 6328 Å soft film; hard film
6, 7. (Vertical reflectivity, %)
8. Highly reflective film
9. 1.06 μm
   soft film
   hard film
10. Hard film strength against laser; greater than 10 billion watts per square centimeter for a laser of 1.06 μm output, normal operation at 200 watts for 1.06 μm continuous laser output from YAG (beam ~ ϕ3)
11. Decreased reflection film
12. For single wavelength in the visible to near infrared region
13. 1.06 μm
    GaA_s window
    Ge window

14. Residual reflectivity ~0.1%
15. Transmittance > 98%
    Transmittance > 90%
16. Strength against laser > 1000 w/cm^2
    Strength against laser > 1000 w/cm^2
17. Interference laser plate
18. Å
19. μm
20. μm
21. Half width 40 ~60 Å
    Transmittance 70-75%
22. Half width about 100 Å
    Transmittance 70-75%
23, Angstrom (Å)
24. Polarization film
25. μm
26. S component transmittance = 2%
    p component transmittance = 96%
27. S component transmittance ~0.3%
    p component transmittance ~98%

Frequently used Q switching and frequency doubling crystals are electrooptic and nonlinear materials. China started the research on these materials relatively early. Xiamen University first investigated amonium dihydrogen phosphate (ADP) as a piezoelectric material in 1957-1958. After laser came on the scene, ADP crystal was quickly used in the research of electrooptic modulation and frequency doubling. Although ADP and potassium dihydrogen phosphate (KDP) do not have ideal modulation coefficient and conversion efficiency, these two materials can be grown into large crystals with good optical uniformity and they remain to be commonly used crystals till now. Beside these two crystals, many research units have grown crystals from new materials like lithium niobate, lithium tantalate, lithium iodide and barium sodium niobate. The table below contains the properties and major suppliers of nonlinear materials.

1 非线性材料的性能统计

2 研制单位	3 晶体名称	4 分子式	5 倍频效率	6 双折射率	7 透过波段	8 研制日期
9 福建物构所 10 山东大学	11 ADP (磷酸二氢铵)	$NH_4H_2PO_4$	14 电光调制，倍频转换，转换效率≈10%	$\approx 10^{-6}$/厘米 16	2100～17000埃 19	1965年 21
	12 KDP (磷酸二氢钾)	KH_2PO_4		$\approx 10^{-6}$/厘米 17		1965年 22
	13 KD*P (磷酸二氘钾)	KD_2PO_4	15 电光调制	$\approx 10^{-5} \sim 10^{-6}$/厘米 18	2500～2×10^4埃 20	1976年 23
24 硅酸盐所 25 江西999厂 26 宁夏905厂	27 铌酸锂	$LiNbO_3$	28 电光调制，倍频转换.	29 $\approx 10^{-5}$/厘米	30 3500～5×10^4埃	31 硅酸盐所在1967年即开始研究
32 山东大学 33 江西999厂	34 钽酸锂	$LiTaO_3$	35 电光调制	36 $\approx 10^{-4}$/厘米	37 3500～5×10^4埃	～1973年 ～1974年
40 硅酸盐所	41 铌酸钠钡	$Ba_2NaNb_5O_{15}$	倍频转换效率≈30% 42	$\approx 10^{-4}$/厘米	3500～5×10^4埃	1976年
46 物理所 47 物构所 48 山东大学	49 碘酸锂	$LiIO_3$	≈15～20%	$\approx 10^{-6}$/厘米	3500～5×10^4埃	1971～1972年

Key:

1. Property statistics of nonlinear materials
2. Research institute
3. Crystal name
4. Chemical formula
5. Frequency doubling efficiency
6. Double refraction index
7. Wavelengths transmitted
8. Development date
9. Fujian Institute of Structure of Matter
10. Shandong University
11. Amonium dihydrogen phosphate
12. Potassium dihydrogen phosphate
13. Potassium dideuterium phosphate
14. Electrooptic modulation, frequency doubling conversion, conversion efficiency ≈ 10%
15. Electrooptic modulation
16, 17, 18. cm
19, 20. Angstrom
21, 22, 23. Year
24. Silicate Institute [Shanghai Institute of Silicate Chemistry and Engineering]

25. Jiangxi 999 Plant
26. Ningxia 905 Plant
27. Lithium niobate
28. Electrooptic modulation, frequency doubling conversion
29. cm
30. Angstrom
31. Silicate Institute started research in 1967
32. Shandong University
33. Jiangxi 999 Plant
34. Lithium tantalate
35. Electrooptic modulation
36. cm
37. Angstrom
38, 39. Year
40. Silicate Institute
41. Barium sodium niobate
42. Frequency doubling conversion efficiency ≈ 30%
43. cm
44. Angstrom
45. Year
46. [Beijing] Institute of Physics
47. Fujian Institute of Structure of Matter
48. Shandong University
49. Lithium Iodide
50. cm
51. Angstrom
52. Year

New nonlinear crystals investigated in the past one or two years also include momohydrade lithium formate, potassium borate, berrylium sulfate, and "Pink Silver Ore".* Fujian Institute of Structure of Matter has investigated organic nonlinear materials and obtained preliminary samples including sulpho sodium salycylate (SN)**. Tests show that SN has a higher nonlinear effect than ADP but not as high as $LiId_3$.

*"Nonlinear material - crystal growth of "Pink Silver Ore," Laser Journal, 1979, Vol. 6, No. 7, 51.

**"Crystal growth and frequency doubling effects of sulpho sodium slaicylate," Proceedings of National Conference on Crystal Growth and Materials Science, 1979, B11, 32.

Due to the ever expanding spectrum of laser wavelengths, the requirements on the increasing variety of laser window materials are also becoming higher. Materials used today include optical glass, NaCl, KCl, Ge, GeA_s, and so on. In addition, calcium fluoride is a good infrared material with a high transmittance, a wide transparent region for the spectrum and a uniform chromatic dispersion. Changchun Institute of Optics and Precision Instruments has recently grown a CaF_2 single crystal which is ϕ 180 mm and weighs 15 kilograms. This crystal is of the advanced international standard. The thallium bromoiodide developed by the Guangzhau Institute of Electronics Technology, China Academy of Science, has reached a transmittance of 60 $\sim$ 70% for 1 $\sim$ 30 micron. Many other research labs have also obtained sapphire crystals of large dimensions and high optical quality.

UPS AND DOWNS

Once lasers came on the scene, applications followed in less than a year. This was faster than any previous technology. People's understanding of a new technology once it appeared and developments of the new technology itself have objective influences on its applications. Laser applications in China have had problems with these two aspects - understanding of the technology and continuous improvement of the technology itself. Therefore, the big rush of laser applications which took place in the past was later adversely affected because some of the performances could not meet the application requirements. With the continuous improvements in laser techniques and with solutions of key problems, applications are again reviving. In other words, applications in certain areas have had a hot period and later cooled down. These ups and downs reflect one aspect of the laser technology developments in China.

In the 1960's, laser technology was still in the preparatory and initiation period, but many good applications were already made in hole-punching, straight line standard and distance measurements. Once in the 70's, the situation in laser applications suddenly opened wide up and, like a big tidal wave, brought intense impacts on various realms of science. This forceful diffusion and proliferation provided new tools for all the disciplines in science and for the economic construction of the people.

I. Industrial Applications

Research on industrial applications began shortly after the successful development of the first ruby laser in China. In 1963, the first demonstrator of a ruby laser hole marking machine appeared in an exhibition in Beijing and attracted interest and attention. In the Chinese clock and watch industry, Shanghai Clock and Watch Plant first made use of laser in their processing work of jewel bearings in 1965 and, after test production runs, the procedure was finally adapted in production and played an important role in it. The photo below shows the jewel bearing production in a factory using laser in hold drilling.

Photo Caption: Production line processes jewel bearings for clocks and watches using laser to drill holes.

Besides watch and clock industry, the technique of drilling holes with laser has also been utilized with good results on Diesel engine nozzles and nylon spray heads. Laser hole-making has been applied for a relative long period of time in China and the technique has achieved some maturity; recently, research has begun on increasing the repetition rate of punching holes and laser outputs for a high repetition frequency of 14 times per sec have been accomplished. If greater improvements can be made on the quality of the output laser beam, the prospects for further proliferation of the technique are excellent.

It has become a well-known fact that lasers can be used in the cutting of hard-to-melt materials such as steel plate, titanium plate, quartz, ceramics, etc. The production of industrial type laser cutting machine, however, requires some more effort. In September 1979, the National Science Committee summoned a characterization meeting in Changchun and characterized the SJ-2500 digitally controlled laser cutting machine jointly developed by the Sedan Branch of Changchun First Automobile Manufacture Plant, Changchun Institute of Optics and Precision Instruments, Tilin Institute for Industrial Design and Chongqing Design Institute of the First Ministry of Machine Building. The capabilities * of this machine are adequate to satisfy automobile industry in the cutting of thin steel plate parts of complex shape and under 6mm thick. The unique features are that its cutting width is narrow (about 0.3mm), it cuts with a clean edge with little oxide residues and the heated area is less than 1mm. In the test production over a two year period, more than 20 different parts made of over 20 materials were processed with a total length exceeding 30,000 meters. Its success has therefore created favorable condition for broad applications in China's ship building and aviation industries.

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* "Digitally Controlled Laser Cutting Machine", Laser Journal, 1977, Vol. 4, No. 5, 17.

It has demonstrated the technique's superiority for small batch, multi-variety production and test production of new products. It thus filled a void in the industrial application of laser processing.

[Photo Caption] Digitally Controlled Laser Cutting Machine

Using laser as a straightness standard has been fairly common in China. Because of the unique character of highly directional, laser provided people with a straight edge which is not bothered by wind or rain. Industry has made good use of various laser rechlinear apparatus, laser transit theodolite, and laser direction finder. They have been used in heavy equipment assembly, sectional building of large ships, assembly of airplane skeleton structure, construction of tall buildings, bridge building, road construction, laying underground pipes, subways, drilling of tunnels, underpasses, and coal mining.

[Photo Caption] Laser transit theodolite used in ship building industry.

Industrial application of laser also includes micro welding, precision measurements and many others. There are more than 40 laser products which are established and in production. Broadened applications are continuously being found for them. The table below lists the major laser products of the First Ministry of Machine Building system.

主要激光仪器产品

产品名称	主要技术性能
JG-II 型自动补偿激光干涉仪	1. 在0~20米可稳定可靠工作; 2. 分辨率0.1微米; 3. 测量精度: 计量室恒温 ±1微米/米 生产车间 ±2微米/米 4. 测量速度: >10米/分 5. 环境参数修正传感器; 气温传感器精度: ±0.1°C(8~32°C) 气压传感器精度: ±1毫米汞柱 (600~800毫米汞柱)
激光丝杠动态检查仪	1. 被测丝杠长度为: 1米、3米和5米三种 2. 精度: 1米内零级 2米内一级
单模稳频激光干涉仪	1. 测量范围: 0~20米 2. 最小分辨率: 0.1微米 3. 速度: 2米/分
激光测长机(1、3米)	1. 测量范围: 0~1000毫米 0~3000毫米 2. 误差: ±(0.2微米+$10^{-6}l$)
高精度丝杠磨床激光自动校正装置	稳定磨削零级精度丝杠
液面法超声波全息探伤实验装置	目前在实验装置上可检查出16毫米厚的铝板内部ϕ1毫米人工孔缺陷的指标
双向激光测径仪	测量范围ϕ5~ϕ30毫米 测量误差<±0.05毫米
激光微区光谱分析仪	1. 相对灵敏度: 0.01~0.001% 2. 绝对灵敏度: $10^{-9}\sim10^{12}$克 3. 取样直径: 10~100微米, 可分析元素不少于60个
CLS-95 型激光平面干涉仪	测定光学零件平面度及小角度 平面度精度 λ/15 平行度精度 1秒
J_{74}-1 型激光膨胀仪	测定金属、非金属材料热膨胀性能 测量精度 ±0.1±10^{-6}/°C

产品名称	主要技术性能
WDJ-1 激光单色仪	1. 调谐范围: 根据需要使用多种染料时3800~7000埃 2. 波长精度 ±1埃, 输出稳定性<0.05埃/°C 3. 可连续更换染料数: 6 4. 输出谱线宽度: 不加标准具 <1埃(在6000埃) 加标准具 <0.1埃(在6000埃) 5. 单脉冲输出转换效率 >8% (光栅、调谐) 6. 光波发散度 θ/2 <5毫弧度 7. 波长校正精度 θ<±0.5埃 8. 波长扫描速度(使用光栅扫描时) 30埃/分, 750埃/分
激光喇曼分光光度计	1. 工作光谱范围: 4000~8500埃 2. 波数重复性: 全波段为 ±1厘米$^{-1}$
J_2-JD 激光经纬仪	1. 测角精度: 水平方向中误差 ±2秒 2. 光束发散度: 100米处光斑直径约5毫米
激光准直仪	最大准直距离: 100米 重复精度: 0.05毫米
JZY-1 型激光指向仪	距离: 1000米 光斑直径: <60毫米
JD-2 型激光指向仪	防爆型, 一次工作距离500米
相位式远程精密测距仪	白天测程40公里以上, 精度 ±(5毫米+0.8×10^{-6}D) 工作温度 0~40°C
短程红外光电测距仪	测程: 0~2公里 精度: ±1.5厘米 工作温度: −15~40°C

[Note: This table is almost all in Chinese, translation see next pages]

Major Laser Equipment Products

Product Name	Major technical specifications	Product Name
JG-IL automatic compensation laser interferometer	1. Stable and reliable operation between 0 and 20 meters 2. 0.1 micron resolution 3. Accuracies: Constant temperature lab ± 1 micron/m production plant ± 2 micron/m 4. Measurement speed: >10 m/min 5. Ambient parameter correction transducers: temperature transducer accuracy: ± 1°C (8 ∿ 32°C) pressure transducer accuracy: ± 1 mm Hg (600-800 mm Hg)	WDJ-1 laser monochromater
Laser silkrod* dynamic monitor	1. Measurable silkrod lengths: 1,3,and 5 meters 2. Accuracy: zeroth order within 1 m first order within 2 m	

(Table continued)

Major technical specifications
1. Tunning range: 3800-7000 Å, different dyes used according to application
2. Wavelength accuracy ± 1 Å output stability <0.05 Å/°C
3. Number of dyes continuously changeable: 6
4. Output spectrum width: without standard: < 1 Å at 6000 Å with standard: <0.1 Å at 6000 Å
5. Single pulse output conversion efficiency > 8% (grating tuned)
6. divergence angle $\theta/2 \leq 5$ mR
7. Wavelength calibration accuracy $\theta < \pm.5$ Å
8. Wavelength scanning speed using grating scan) 30 Å/min, 750 Å min

(Table continued)

Single mode, stable frequency laser interferometer	1. Measurement range: 0-20 m 2. Minimum resolution: 0.1 micron 3. Speed 2 m/min	Laser Raman Spectrophotometer
Laser length measurement apparatus (1, 3m)	1. measurement range: $0 \sim 1000$ mm $0 \sim 3000$ mm 2. Error: $\pm$ (0.2 micron + 10^{-6} l)	J2-JD laser transmit theodolite
Laser automatic calibration device for high precision silkrod grinding machine	Stable grinding of zeroth order precision silkrod	Laser straight-line standard JZY-1 laser direction finder
Liquid surface method ultrasonic holographic flow detection experimental device	On experimental set up, in the interior of 16 mm thick aluminum plate, ϕ 1 mm hole artificial flaw can be detected	JD-2 laser direction finder Phase type long range precision distance measuring device
Bidirectional laser caliper	measurement range ϕ 5 $\sim$ ϕ 30 mm measurement error $< \pm 0.05$ mm	

(Table continued)

1. Operation spectrum range: 4000-8500 Å 2. Wave number reproducibility: $\pm$ 1 cm^{-1} over entire range
1. Accuracy in angle measurement: ± 2 sec in horizontal direction 2. Beam divergance 5mm dia. light spot at 100m
Maximum distance 100 m Reproducible accuracy 0.05 mm
Distance 1000 m light spot diameter < 60 mm
Explosion proof model, one time working distance 500 m
Day time range 40 Km or better Accuracy $\pm$ (5 mm + 0.8×10^{-6} D) working temperature 0 ∿ 40°C

(Table continued)

Laser micro-scopic spectrum analyzer	1. Relative sensitivity: 0.01 ∿ 0.001% 2. Absolute sensitivity: $10^{-9} \sim 10^{12}$ gram 3. Sample diameter: 10-100 micron Over 60 elements analyzed	
CLS-95 laser plane-interferometer	Measures flatness and small angle of optical components flatness accuracy $\lambda/15$ parallellism accuracy 1 sec	Short range infrared photoelectric distance meter
J_{74} -1 laser dilatometer	Measures thermal expansion properties of metallic and non-metallic materials with accuracy of $\pm 0.1 \pm 10^{-6}/°C$	

(Table continued)

	Range: 0 ~ 2 Km Accuracy: ± 1.5 cm Operating temperature -15 ~ 40°C

II. Agricultural Applications of Laser

China started its research on agriculture applications of laser relatively late (around 1972). Currently, there are more than 100 units and departments in about 20 provinces, municipalities, and autonomous prefectures engaged in this effort. Among them, Guangdong province, Hunan province and Sichuan province are most active. In Guangdong province, 80 units with status of commune and above (130 units counting production teams) have carried out experimentations. There have been two national forums on the agricultural applications of laser, once held in Foshan, Guangdong, in December 1974 when 18 provinces, municipalities, autonomous prefectures and 81 branches and departments participated in the meeting sponsored by the Chinese Academy of Science. The second meeting was held in Beijing in December 1975 with 115 representatives from 80 units in 25 pronvinces, municipalities and autonomous prefectures.

Seeding experiments using laser have been performed on about 100 species of 20 varieties of grain crops, industrial crops, vegetables, fruit trees and silkworm. Laser radiation experiments have also been performed on animals such as pigs, chickens, fish and microbe. Concrete results have been obtained on rice, rape, and silkworm. For example, the KEJI No. 1, 2, 27, 28 and 29 breeded with laser radiation have resulted in a 60-100 jin increase of output per mu; rape seeds have also enjoyed increases in production after laser treatment. In Qingpu county, Shanghai, one tenth of the rape field (9000 mu) is planted with rape breeded using laser and the average production increase is 10-25% per mu.

New species of domestic silkworm and castor oil plant silkworm selected by laser induced changes have now been raised to fifth and thirty first generations respectively. The new species of domestic silkworm are larger in size and produces 18% more silk than the control group. Several transformations

in form and character appeared in the new species of castor oil plant silkworm which are larger in size and can stabilize heredity.

Forest insecticidal efficiency has been raised to above 60% using strain selected in laser breeding whereas for the control strain it had only 30% in contrast.

In summary, some results are observable after a few years of preliminary experimentation. For example, laser radiation of crop seeds can speed up germination, produce robust seedlings, shorten the time of maturity, increase resistance against diseases and insects, and cause variation in the descendants. Many results still need further experimental confirmation. All regions are looking forward to further strengthening of organized and planned scientific investigation so that a new technological avenue can be opened in the Chinese agriculture.

III. Research on Medical Applications of Laser

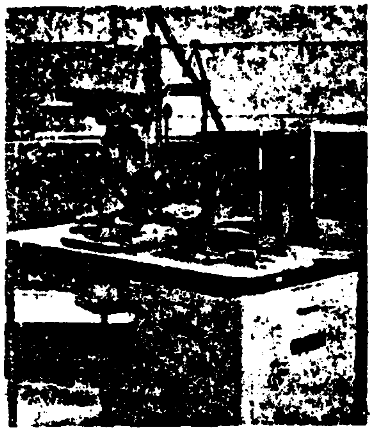
China started medical laser research relatively early. Ruby laser medical treatment machine was developed in 1965 and animal tests were done on domestic rabbits, guinea pigs, dogs and monkeys. Shortly after that, CO_2 laser medical units were used in the cutting of body surface and removal of inner organs. In 1970, there has been wide spread clinical treatment of diseases using laser. Currently there are about 200 places in China where clinical experiments using laser are being developed (including 50 plants involved with research and development of medical instrumentation and 40 scientific research units). Many more institutes are using laser in medical treatments of more than 130 different diseases. Considerable clinical experience has been accumulated in ophthalmology, dermatology, gynecology, onocology and acupuncture. In ophthalmology, the laser iridectomy work has attained advanced international standard.

Cancer treatment using laser has also received some emphasis of the Chinese medical profession and the laser treatment of skin cancer has had good results. In one hospital in Shanghai, laser gasification has been used in the treatment of 73 cases of tumor and the overall effectiveness was 96%. Among the 73 cases, 40 were abandoned by conventional methods (they did not respond to surgical operation, anticancer drugs and radiation therapy); two year survival rate after laser gasification treatment was 76.7% and 22 cases returned to work or normal life. Among 26 cases which are treatable with conventional methods, the two year survival rate after laser gasification treatment was 96.2%.

Clinical practices of the recent years have also indicated that He-Ne lasers are effective in treating acute inflammation and peptic ulcer and CO_2 lasers are 90% efficient in treating vascular nodule, pigmented moles, and flat warts.

To promote the research of laser medicine, a national forum on laser medicine and laser medical instrumentation was called in June 1977 in Wuhan. 410 representatives from 243 units in 23 provinces, municipalities, and autonomous prefectures attended the meeting. In addition, many provinces and cities have also had their own meetings on laser medicine.

The medical use of laser in China started with ophthalmology. Now there are about 20 institutes in 16 provinces, cities and autonomous prefectures doing research and development of laser ophthalmology instruments and treating more than 20 different kinds of eye ailments; among them, the treatment of glucoma, cataract, retina vascular nodule, retina coagulation re-attach, iridectomy, and closing retina ruptive have been relatively effective and the technique gained some degree of maturity.



Model JG-75-1 iridectomy machine

CO_2 and YAG lasers are effective in the burning and cutting of tumors in the oral and facial regions. They are effective especially in treating vascular tumor in these places because the conventional radiation method, cryosurgery, and hardener injection are all less than satisfactory. Ordinary surgical removal often causes functional disability or abnormality. Laser treatment is not only clinically sound but also leaves no functional disability problems and keeps the integrity of the facial shape.

CO_2 laser medical unit used in burning operation

Acupuncture is a traditional and widely popular medical technique of China. It has been a long history of several thousand years. Light has a stimulating effect on the acupuncture points and has been used in modern physical therapy. After the invention of laser, medical workers naturally thought about the experiment of using laser as an acupuncture tool. Research in this area began in China in 1976. Laser acupuncture machines using He-Ne laser, CO_2 laser, YAG laser and N_2 molecule laser have performed over one thousand cases of clinical tests and demonstrated the effectiveness of laser acupuncture. The technique is definitely effective in the treatment of nail groove inflammation. With 93.3% efficient and 75% cure rate, patients with this disease need no longer endure the agony of nail pulling. Besides it also has had good results in treating the cloudiness of eye ball vitreous body, hypertension, asthma and enlargement of the neck bones.

IV. Other Applications

The birth of laser and the subsequent theoretical developments have profoundly affected the entire realm of optics. Scientists have called the appearance of laser the "Renaissance of optics". Laser has proliferated into all the branches of science and technology. One of the most successful applications of laser is that in spectroscopy. After laser was used in classical spectroscopy, the resolution suddenly improved by a millionfold. Today, the ultrahigh resolution spectroscopy centered around laser has gradually developed into a new branch of science. It is not exaggeration when scientists say that laser has caused a revolution in spectroscopy.

China's scientists have been actively engaged in laser spectroscopy research and have obtained commendable achievements. For example, using mode-locking ruby laser in the excitation of benzene, seven orders of Stokes' lines and a Sharp first order anti-Stokes' Raman spectrum have been observed. In addition,

some new phenomena were observed also. According to stimulated Raman theory, lower order spectrum lines should appear first and then partial spectrum appears. Furthermore, the intensity of the spectrum lines should decrease with increasing order. However, "order jumping" phenomenon* was observed in the experiment. Often the fifth order spectrum lines were observed but those of the third and fourth orders were not; or, the intensity of the fifth order spectrum was stronger than that of the third and fourth order.

Preliminary observation of the 10th order Stokes' stimulated emission from 5460 -6840 Å has been made using electrooptically switched frequency multiplication YAG: Nd laser passing through multi-mode quartz optical fiber. This could be a simple variable frequency laser.

There has also been good results in the research of frequency multiplication. Using multiple frequency pulsed laser to simulate organic dye solution, four wave frequency mixing effects have been observed.

Chemical applications of laser has aroused high interests among Chinese scientists. Of particular interest is the laser separation of isotopes. Organized research on this subject was begun in early 1970's and some results have been obtained.

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*"Observation of high order stimulated Raman scattering", Laser Journal, 1978, Vol. 5, No. 5-6,22.

In 1976, separation of sulphur* from sulphur hexafluoride has been successfully carried out using pulsed CO_2 laser; subsequently, the boron isotope B^{10}** was separated from boron trichloride and isotope deuterium*** was separated from methal aldehyde. At present, Chinese scientists are also investigating a new method for uranium isotope separation using laser.

In the area of optical fiber communication, China has entered the stage of applied research and optical fiber transmission of telephone and television has began field testing. A 5.7 Km 120 channel telephone experimental system has been in use and maintained good performance after 2000 hours of continuous use. The average attenuation of communication optical fibers has been reduced down to 5 dB/Km.

UPWARD BOUND

After more than a decade of development in the laser technology, people have gained more profound understanding of its nature; in the meantime, more and more new questions are raised in the process of actual applications. These questions are urgently waiting for solutions and break-throughs before further technological advances can be made. In another aspect, the gap between Chinese laser technology and development in foreign countries has also been recognized and there has been an urgent call for "upward bound" in basic research to close the gap.

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* "Isotope separation using TEA CO_2 laser", "Laser separation of sulphus isotope", Laser Journal, 1978, Vol, 5, No. 5-6, 13.

** "Separation of boron isotope using infrared multiphoton absorption method", Laser Journal, 1978, Vol. 5, No. 5-6, 14.

*** "Multiphoton Separation of methan aldehyde concentrated deuterium", Sichuan University XUEBAO (Natural Science edition), 1978, No. 4, 63.

Under the policy of "Emphasize the fundamental and stress the sophistication", research has opened up in many areas. The Guangzhou "Fourth National Laser Science Reporting Conference" held in 1978 was one of the large scale research exchanges in laser science. The Guangzhou conference has the following overview and unique features: (1) papers on theoretical analysis have increased, (2) emphases have been placed on the research and development of new types of devices, (3) there has been an increase of the topics which fill voids in China, (4) research on the improvement of device properties has been strengthened, and (5) there were new improvements in the quality of both theory and experiment. These are extremely encouraging new signs as they reflect the total realization of what the late Premier Zhou had repeatedly preached: "Move the scientific research upward with a broad, deep and practical foundation", and strengthen the spirit of basic theoretical research.

During the Guangzhou meeting, there were exchanges of results of the past few years on the foundamental laser research and some applied laser research. Many current key academic problems in laser research and the future direction were also discussed. Among the 250 academic papers and research reports presented in the meeting, many have demonstrated scientific research achievements which are of relative high standard. For example, the one-dimensional physical model for implosion in laser nuclear fusion has unique features and its calculations are in reasonable agreement with experiments. In the area of photon-atom and photon-molecule interactions, limitations of the perturbation theory were pointed out and new calculation methods were proposed which are more appropriate for strong (high energy) photon condition. In the fundamental experimental study of laser fluorescence and laser plama X spectrum, new phenomena observed are worthy of further investigation. A broadened research effort is underway in areas intimately related to the technical development of laser such as resonance cavity theory and non-linear transport of laser in medium. There were also high quality

papers presented in the information processing area. Information capacity concepts were adequately dealt with and received attention of the participants. In the branch of laser material, thorough investigations of the materials' fundamental physical properties as well as advances in industrial technology have taken place.

All in all, the Guangzhou conference* has had a pivotal effect in the history of the development of laser science and technology in China. It summarized the past and affected the future direction, indeed it was the largest meeting in our laser history.

(To be Continued)

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*"A big meeting in laser science research", Laser Journal, 1978, Vol. 5, No. 5-6, 1-2.